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Financial Viability of Underwater Heart Rate Monitoring

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Financial Viability of Underwater Heart Rate Monitoring

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ABSTRACT

More than 3,000 divers are treated for decompression sickness each year, with many more untreated and unreported.[1] Decompression sickness develops during the ascent of a dive as bubbles of nitrogen, which were absorbed during a dive, expand and cause tissue damage.[2] Students at Worcester Polytechnic Institute are currently developing a new method of avoiding decompression sickness using pathologic indicators in a subject's electrocardiogram. The purpose of this particular project was to determine whether underwater heart rate monitoring (UHRM) is financially viable in the diving market. Based on the research conducted in this review, UHRM shows some promise, particularly in the military market. Moving forward, the inventors will need to complete development of the product and all of its components and build awareness of its capabilities.

Executive Summary

Decompression sickness (DCS) is a condition developed during the ascent of a self contained underwater breathing apparatus (SCUBA) diver, and reportedly affects 3,000 divers worldwide each year.[1] This does not accurately reflect the scope of the problem, however, because not all divers who have succumbed to DCS seek medical attention.[3] Foregoing medical treatment does not imply that the condition is something to be taken lightly. DCS can range from a simple skin rash, to headaches and vomiting, to death.[4]

New advancements have been made in the area of DCS prediction and prevention using underwater heart rate monitoring technology (UHRM). A group of students at Worcester Polytechnic Institute (WPI) have developed a device which detects the onset of DCS using pathological factors found through an electrocardiogram reading. Using data analysis and DCS detection methods developed by the students' advisor, Professor Ki Chon, the device is the only one of its kind.

There are currently several products on the market for DCS prevention which use theoretical models to predict the onset of DCS. Unfortunately, all of these current products are inadequate because they can only predict the probability of DCS and often do not provide a continuous feedback loop to the diver. With so many variables affecting person's susceptibility to DCS – hydration, fitness, and fatigue to name a few – it is extremely difficult for theoretical-based methods to give a perfect recommendation every time.[5] These products include:

- Navy dive tables, which provide standard recommendations based on the length of time to be spent in the largest depth

- Dive computers, which provide custom recommendations during each dive, based on the time to be spent at each depth
- Dive software, which allow the user to plan a dive ahead of time, factoring in the temperature of the water, the fitness of the diver, and the length and depth of the dive

Professor Chon has requested this investigation to determine whether a strong market potential for the UHRM device exists and what steps should be taken to increase commercial success. After providing an overview of the physiology, the systems and the cost drivers of the device, this investigation discusses the possible market segments and analyzes the viability of UHRM by calculating the break-even point and return on investment for each market. This investigation also included an in-depth SWOT analysis.

Analysis has shown that, even with the limited scope of research and development to date, UHRM has a promising future. However, a modified heart rate monitor must be developed for the UHRM device to be marketable. The technical diving community and military must be made aware of the advancements made by the technology in addition. Lastly, the intellectual property associated with UHRM must be registered and protected. The critical steps outlined above must be taken quickly in order to capitalize on this new, exciting opportunity.

EQUATIONS

FIGURES

TABLES

I. INTRODUCTION AND PROBLEM STATEMENT

Decompression sickness (DCS) is a condition which can be developed during the ascent of a diver who uses a self-contained-underwater-breathing-apparatus (SCUBA).[2] As the diver ascends, the nitrogen which entered his body at lower depths and increased pressure expands and bubbles, damaging interstitial tissue during the process. There are four reported cases of DCS per 10,000 dives, but many more cases go unnoticed because the divers do not seek medical attention.[1] Foregoing medical treatment does not imply that the symptoms are not severe however. DCS can range from a simple skin rash, to headaches and vomiting, to death.[2]

To prevent DCS, divers pause at several points during the ascent in what are called decompression stops. These resting periods allow the nitrogen to escape the body, and thereby prevent any tissue damage. Every dive is different, and the amount of time spent at each stop is affected by many factors, including the deepest depth, the amount of time spent submerged, and characteristics of the diver such as fitness, hydration levels, and fatigue[4]. Currently, divers rely on products such as dive tables, dive computers, and dive planning software to theoretically predict what will be necessary to avoid DCS during a dive, but these theoretical predictions often fall short. Just over 2% of those who use more conservative plans than those given by the dive tables will still experience DCS.[6] Theoretical prediction is inadequate.

Worcester Polytechnic Institute students (Sebastian Courtney, Justin Bales, and Alex Reeves) under the direction of Professor Chon have worked to develop a new Underwater Heart Rate Monitoring (UHRM) device which detects the onset of DCS by analyzing pathological findings of the electrocardiogram (ECG).[7] The device consists of two waterproof electrodes which pick up bioelectric signals from the subject and transmit them to a modified heart rate monitor, which analyzes the ECG waves and then alerts the diver if he shows signs of DCS, and an elastic vest, which holds the system in place. This new device allows the diver to respond the alerts presented by the device and adapt his decompression speed as necessary.

Although this technology is revolutionary in its ability to detect DCS rather than theoretically predict it, there are still many factors which must be considered. The product's ability to stand up to its competitors and penetrate the diving market is important, but UHRM cannot be considered a contender in the market until the modified heart rate monitor is developed. Through the use of research, comparisons, and analyses, this paper suggests that UHRM is worth pursuing and recommends pathways toward its success.

II. METHODS

In order to determine whether or not the pursuit of UHRM is worthwhile, a comprehensive strategic analysis was conducted regarding the device's competitiveness, market feasibility, and financial strategy. This strategic analysis relied on a broad review of background information of UHRM and competing technologies, gathered through:

- Interviews with Industry Experts
    - Heather Knowles, Co-founder of Northern Atlantic Dive
    - Sue Porter, Statistics Analyst of the Professional Association of Diving Instructors (PADI)
    - Pamela Halvorsen, a commercial realtor in the greater NH area

- Gerry Blodgett, J.D. LL.M., an intellectual property (IP) attorney

- Interviews with the design team
- Scholarly articles

These sources provided the foundation for the SWOT, break even, and return on investment analyses. The SWOT analysis was created to evaluate the device's competitiveness. To analyze the market feasibility and financial strategy, a break even analysis and return on investment analysis were conducted (Equation 1 and Equation 2).

EQUATION 1: BREAK EVEN ANALYSIS

$$break\ even\ unit\ quantity = \frac{C_f}{P - C_v}$$

$$P = price\ of\ goods; C_v = Variable\ Costs; C_f = Fixed\ Costs$$

EQUATION 2: RETURN ON INVESTMENT ANALYSIS

$$ROI = \frac{x * (P - C_v) - C_f}{C_v * x - C_f}$$

$$x = goods\ sold$$

For public access, this report is stored on WPI's project website. Those interested can search for the author's name in Google with the key words *underwater heart rate monitoring*.

III. RESULTS

The conducted analyses determined that it would be worthwhile to continue development of UHRM based on the following conclusions:

- More than 1.2 million worldwide could benefit from UHRM devices during dives, with preliminary market segments approximating to 270,000.[8,9]
- The pursuit of UHRM in the technical diving and military market segments is low risk, with the break even number of customers averaging around 2% of the market size.
- Although the author recognizes that penetrating 10% of the market after three years is aggressive, if the company achieves this, investors can anticipate up to a 34% return on investment after three years

These results are discussed at length below.

IV. Discussion

The basic physiology of the cardiovascular system and its response to underwater diving is discussed together with an overview of the UHRM system, its market feasibility, and financial strategy.

IV1. Physiology of the Systems

In order to further understand the necessity for UHRM it is important to review the physiologic aspects of SCUBA diving and ECG monitoring.

IV1.1 Physiology of SCUBA Diving

SCUBA diving is an activity which enables people to visit an environment that they are not physiologically capable of visiting otherwise – journeying underwater for greater than the time which holding their breath allows.[10] The dangers of SCUBA are evident as soon as the diver submerges. The underwater environment is a hostile one, in which divers are surrounded by a substance which they cannot breathe: water.

Dangers become increasingly prevalent the deeper the dive. This is because the atmospheric pressure a diver endures increases as he descends by one bar per ten meters of water.[2] One bar is equivalent to the pressure produced by Earth's atmosphere, but water is much denser than air. A diver 10 meters below the surface will experience twice the ambient pressure as he would on land.

The changes in pressure affect the volume of the air in the diver's lungs. Boyle's Law of Gas and Pressure, shown in **Error! Reference source not found.** explains this event.[11] The volume of a specific quantity of gas is inversely proportional to the ambient pressure. If a specific quantity of air is subjected to double the ambient pressure, the air will take up one half of its original volume. Conversely, a diver only 10 meters below the surface must be sure to expel the air on the ascent in order to prevent the air in his lungs from expanding to twice its original size, causing them to explode.

EQUATION 3: BOYLE'S LAW OF GAS AND PRESSURE

$$PV = k \rightarrow P = \frac{k}{V}$$

Divers must breathe air supplied in pressurized tanks because a diver's lungs would not be strong enough to otherwise pull the air from the tank. Instead, the pressurized air expands as it leaves the tank, allowing the diver to inhale.

The ambient pressure also creates danger in relation to the partial pressures of the air breathed by the diver (Equation 4).

EQUATION 4: PARTIAL PRESSURE

$$P_x = \frac{n_x}{n} * P$$

If the partial pressure of nitrogen surpasses approximately two bars, the diver becomes susceptible to nitrogen narcosis.[2] Symptoms of nitrogen narcosis worsen as the partial pressure of nitrogen increases, but usually reverse after the diver has resurfaced. Problems arise from nitrogen narcosis because divers are more susceptible to mistakes. Any mistake when a diver is submerged can be deadly.

TABLE 1: NITROGEN NARCOSIS SYMPTOMS AT EACH PARTIAL PRESSURE

Partial Pressure of Nitrogen (Bars)	Symptoms
2-4	Intoxicated, euphoric stupor
6	Sleepiness, hallucinations, impaired judgment
8	Confusion, delayed response to stimuli
10+	Unconsciousness

.

Advanced divers who plan to journey deeper than 30 meters may seek to prevent nitrogen narcosis by using Nitrox or Trimix: gas mixtures with different concentrations of oxygen and nitrogen than surface air.[2] The standard concentration of the air we breathe at the surface is 21% oxygen and 79% nitrogen.[12] Nitrox uses a higher concentration of oxygen while Trimix replaces some of the nitrogen with helium.[4]

In raising the concentration of oxygen in the tank, a diver must also be careful to avoid oxygen toxicity, a condition which develops when a person breathes high partial pressures of oxygen.[13] Oxygen toxicity is in essence an overdose of oxygen and can affect either the lungs or the central nervous system (CNS). Pulmonary oxygen toxicity can result from a person breathing a partial pressure of 0.5 bar of oxygen for a prolonged period of time.[2] This would be the equivalent to breathing the standard surface air at 14 meters below the surface. The oxygen irritates the lungs, causing inflammation, with symptoms including cough, tickle in the throat, and fever. A person breathing a partial pressure 1.6 bars of oxygen, the equivalent of breathing 50% oxygen 22 meters below the surface, is at risk for CNS oxygen toxicity, which will most often result in a seizure. CNS oxygen toxicity can be fatal because these seizures most often occur underwater, causing the diver to drown.

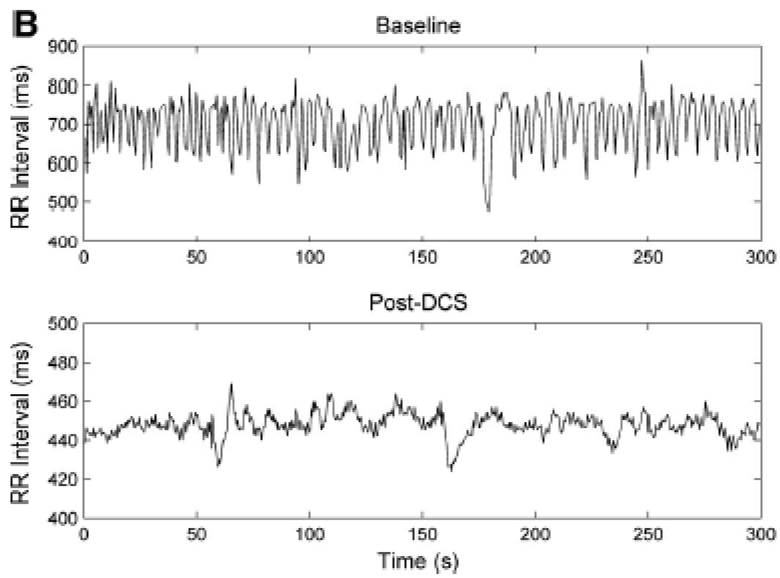
IV1.1.1 PHYSIOLOGY OF DCS

The most prevalent threat experienced due to high partial pressures of nitrogen is decompression sickness, DCS.[4] This is the result of too much nitrogen being absorbed by the diver and too little time spent pausing at decompression stops along the diver's ascent to the surface. Every diver who breathes air mixtures containing nitrogen absorbs the chemical during his dive.[2] The longer the diver spends submerged and the deeper his journey, the more nitrogen absorbed. If the diver resurfaces without allowing the gas to escape at each level of ambient pressure, the densely packed nitrogen inside his body will expand and bubble. This expansion can create tissue damage and arterial gas emboli.[14] Symptoms can be as minor as skin irritation or as severe as death.[4]

Current methods to prevent DCS focus on tracking the amount of nitrogen that has entered the body during a dive using theoretical predictors. These methods are often inadequate because of the several factors which play into the development of DCS. In addition to the time spent under water and the time spent at the deepest portion, a diver's fitness, weight, hydration, and carbon dioxide levels, and the temperature of the water will all affect a person's susceptibility to DCS.[5]

Pathologic indicators for the onset of DCS were discovered in 2009, creating the opportunity for a new method of DCS prevention.[15] The onset of DCS manifests itself in decreased heart rate variability of a subject. Normally, the heart rate changes almost constantly due to changes in the sympathetic and parasympathetic nervous system (homeostasis).[16] When the heart goes into distress, due to the onset of DCS for example, the heart rate becomes much more constant (Figure 1: A comparison of baseline homeostasis versus post-dcs homeostasis).

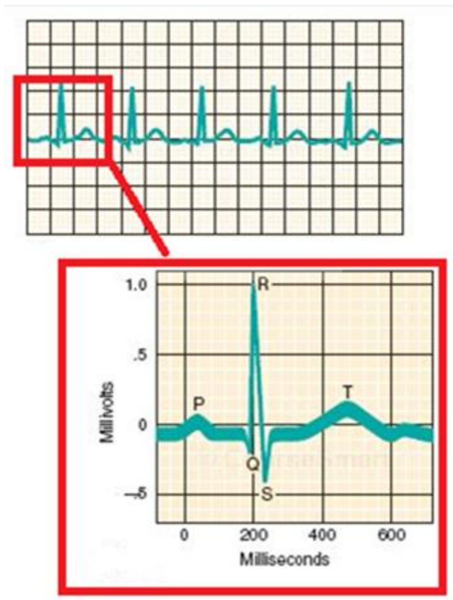
FIGURE 1: A COMPARISON OF BASELINE HOMEOSTASIS VERSUS POST-DCS HOMEOSTASIS[15]



IV1.2 Physiology of the ECG

An electrocardiogram is a device which records changes in potential across the heart, signals which are conducted through the body's fluids.[17] The ECG converts the bioelectric signals into waves representing the potential's value, plotting them in a manner as shown below.[18] When cardiac tissue is at resting potential, the wave is flat, but when depolarization and hyperpolarization occur, the wave will go above or below the line respectively.[17] The wave of the electrocardiogram is divided into five distinct parts: P, Q, R, S, and T.

FIGURE 2: ECG WAVE IN DETAIL



Wave	Physiologic Phenomena
P	Sinal atrial node fires; atria fibers depolarize; atria contracts
Q	Atrial fibers hyperpolarize; atria relax
R	Ventricular fibers rapidly depolarize; ventricles contract
S	Ventricular fibers hyperpolarize
T	Ventricular fibers repolarize; ventricles relax

When calculating the heart rate, analytics most often focus on the R waves, which tend to be the easiest for software to detect.[19] The R-R interval, as referenced in the Y Axis of Figure 1, is the length of time between two R waves. Plotting each interval versus time visually portrays the heart rate variability of the subject.

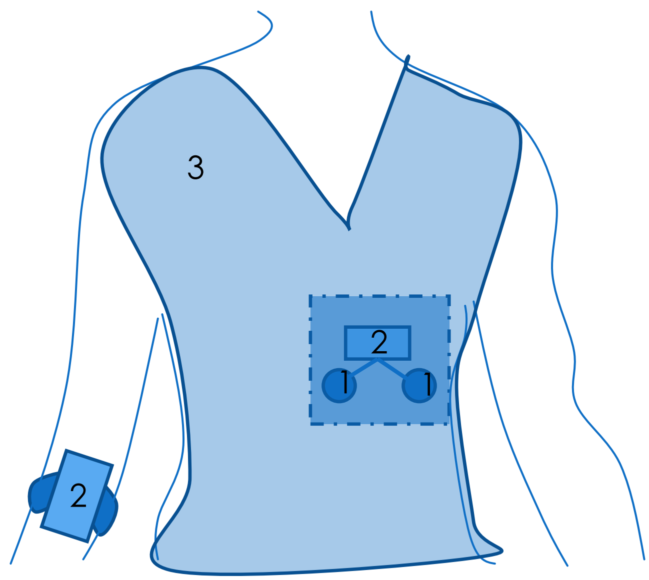
IV2. Business Principles

Underwater Heart Rate Monitoring opens new doors to DCS prevention. Whereas in the past, in which divers had few options and were limited to follow general guidelines based on theoretical analyses, UHRM allows them the opportunity to adapt underwater in real time. This is the first device of its kind: one which uses actual pathologic indicators, i.e. measurements of heart rate variability, to determine the onset of DCS.

IV2.1 Overview of UHRM

The UHRM device monitors a subject's heart rate variability while he is submerged, alerting him if he begins to show signs of decompression sickness. The system, shown below, comprises three sets of components: (1) two waterproof electrodes which sit on the upper left abdomen, (2) a modified two-part heart rate monitor, which analyzes the ECG signals and conveys the risk to the subject, and (3) an elastic vest which holds everything in place.

FIGURE 3: DIAGRAM OF UHRM DEVICE PACKAGE



The waterproof electrodes are adapted from a set developed by Barrows et al in 2010. The original Hydrolectrode is a 10 square centimeter system which uses the Convatec Sur Fit Gasket as its base component.[20] The gasket features a plastic spine and a Stomahesive barrier, chosen because of the gasket's ability to withstand the elevated ambient pressure while minimizing damage to the patient's skin during removal. The modified Hydrolectrode would use similar components as its predecessor, but would license the technologies rather than using entire Sur-Fit gaskets.[7] Specifically, the project group would look into licensing Convatec's Durahesive ® technology, because of its ability to withstand ambient pressure and liquid.[21] Unlike their counterpart, the Stomahesive barriers become compromised with extended exposure to liquids.

The heart rate monitor is a modification of the Omron HR-100C Heart Rate Monitor. This monitor is a two part product featuring a chest transmitter which picks up the heart rate signals and a digital display mounted on a wristband which receives the data. One modification performed on the heart rate monitor is the removal of the straps of the chest piece so that the monitor sits snuggly in a waterproof pocket of the vest.[22] The chest piece is also be modified to receive signals from the waterproof electrodes rather than the original sensors on the device. The final modification to the system is that the wrist-display's software will be altered to analyze the R-R intervals of the heart rate data and then alert the patient of the onset of DCS when it exists.

The project team working on this device has not yet developed the heart rate monitor and has substituted a waterproofed halter monitor in its place to test the electrodes and vest. If the electrodes and vest prove viable, the team will consider developing the accompanying device. The author chose to assume that the heart rate monitor would be developed to the specifications given above.

The elastic vest is a reusable vest which the diver will put on underneath his wet suit, modified from a product by Patagonia, the R2 Reversible Vest. The R2 Reversible Vest is a fitted neoprene (two millimeters thick) vest available in sizes small, medium and large for each gender.[23] For UHRM, the vest is modified to include a waterproof pocket to hold the monitor snuggly in place. The pocket has two perforations on the proximal side for the electrode leads.

IV2.2 Marketing Segmentation

UHRM has applications in several niches in the SCUBA industry, with some more feasible than others. The main areas that could benefit from UHRM are recreational, commercial, and military diving.

IV2.2.1 Recreational Diving

Recreational diving encompasses all diving activities related to leisure and can range across the spectrum of experience. At one end of the spectrum are resort-divers, those who participate in a diving excursion during a vacation, who have very little preparation or experience with SCUBA; and, introductory divers, those in the process of getting their first open-water certification.[24] These two groups are probably not feasible to pursue as markets for UHRM at this time because of the perceived low user commitment of these activities. If UHRM proves successful with its other market endeavors, eventually the technology could trickle down to the less complex diving activities.

At the other end of the spectrum lies advanced technical diving. Technical diving, or diving which involves advanced technical procedures to enable divers to reach larger depths or more complex routes, such as caves, is a recreational diving market segment which would be feasible for UHRM.

IV2.2.1.1 Technical Diving Market Size

Although the exact number of active technical divers, or technical divers who participate in diving activities at least five times a year, is not available, approximations can be made using other market data.

PADI reports that approximately 135,000 people were certified members with the organization in 2010, 3,000 of whom became certified through PADI's Tech Rec courses.[8,25] Assuming that PADI's proportion of technical divers to its total population is a reflection of that of the recreational diving population as a whole, one can estimate that there are approximately 264,000 active technical divers worldwide. This estimation is based on the population estimate by *Undercurrent Magazine* in 2007, which suggested that there were approximately 1.2 million people worldwide who dived recreationally five times a year or more.[9]

IV2.2.1.2 Products for Active Technical Divers

It is estimated that active technical divers would use the product five times a year on average, leading to the following product plans. A starter pack, containing the vest (available in both male and female), the monitor, and twenty electrodes, would be the primary item marketed. The disposable electrodes would last the diver ten dives, or an estimated two years. In addition to the starter pack, electrode refill packs will be sold, each containing six electrodes, yielding three more dives.

IV2.2.2 Commercial Diving

Commercial divers are those who dive as an occupation. Industries which hire commercial divers include construction, demolition, oil, police and fire departments, and underwater salvage companies.[26] These divers submerge on almost a daily basis and visit depths greater than the average recreational diver, subjecting themselves to heightened chances of risk. After visiting such a deep atmosphere, the employees visit a hyperbaric chamber to decompress.

Commercial diving companies could benefit from UHRM by using it to tailor the length of time spent in the Hyperbaric Oxygen Therapy (HBOT) chamber to the detected risk of each employee. This would prevent on the job injuries, lower costs associated with workman's compensation, and reduce the time spent in the HBOT to what is necessary.

Although there is incentive for commercial diving companies to use UHRM, it is not a feasible market to pursue at this time, because of the low number of commercial divers. The US Bureau of Labor Statistics reports that there are 3,720 commercial divers in the United States.[26] This is not a large enough population to warrant pursuit in the short run, but eventually, the company could offer the devices in bulk to commercial diving organizations.

IV2.2.3 MILITARY DIVING

The Navy has a division in its Special Operations Forces referred to as the Navy Divers.[27] There are four main areas of responsibility for Navy divers: salvage and recovery, in which divers work to find and retrieve wreckage; deep submergence, in which divers submerge to "the greatest depths in name of research and classified missions;" ship husbandry, in which divers fix and maintain the Navy's fleet; and saturation diving, in which divers live at extreme depths for long periods of time. The Navy strives for a less than 2% prevalence of DCS during its dives.[15]

IV2.2.3.1 Military Diving Market Size

The size of the military diving market is classified information, and was not available through pursuit of the Freedom of Information Act. Accordingly, the author chose to arbitrarily assume that this population would be approximately 1,000 and that these individuals dive on average approximately 200 times a year. Although the approximation of the military population is less than that of commercial diving, the military will be more likely to pay a higher premium for a quality product and invest in its servicemen, thereby making it a more feasible market to pursue.

IV2.2.3.2 Products for Military Use

Based on the estimation that military divers will dive approximately 150 times a year, the product packages marketed to the military are substantially larger than those marketed to civilians. Vests will be offered in batches of 20, with a size and gender specified for each vest in the batch. Monitors will also be offered in batches of 20. Electrodes will be offered in packages of 600.

IV2.2.4 Price, Promotion, and Placement of Products

The prices for each product with its designated market are listed in Table 2: Product price matrix for technical and military diving markets. For the technical diving market, these prices were chosen based on current prices of competing technologies and anticipated usage by customers. Technical divers would mostly likely spend on average $1000 on UHRM equipment over a span of five years, a figure comparable to that of a technical dive computer.[5] The pricing of the starter pack is based on a per electrode price of $20, with the vest and monitor included at no additional price. The refill pack also reflects a per electrode price of $20. For the military market, the author chose to use the same per electrode price and created per unit prices of $100 for each vest and monitor. For both markets, this would put the burden of the firm's profits on the consumable portion of the product, similar to the strategy of Gillette's disposable razor cartridges.[28]

TABLE 2: PRODUCT PRICE MATRIX FOR TECHNICAL AND MILITARY DIVING MARKETS

Market	Product	Price
Technical Diving	Starter Pack	$400
	Refill Pack	$120
Military Diving	Vest Pack	$2,000
	Monitor Pack	$2,000
	Electrode Pack	$12,000

To build awareness about the UHRM product line, the company should register for diving trade association shows – the Dive Equipment and Marketing Association (DEMA), Dive Alert Network (DAN), and Scuba Industries Trade Association (SITA) – and apply for advertisement space in diving magazines such as *Undercurrent*, *Advanced Diver Magazine*, and *Immersed*, an international technical diving magazine.

IV2.3 Cost Drivers and Analysis

The costs to manufacture the UHRM devices will depend on both variable and fixed costs.

IV2.3.1 Variable Costs

If the company uses current production techniques for creating the product, it is possible to anticipate the approximate costs for each component. Costs of materials were approximated through the use of online suppliers and include shipping when necessary.

Cost of labor is based on the standard $8 rate of paying a work study student to perform the work.

Each electrode uses one Durahesive Skin Barrier, one Vermed electrode, half a sheet of Scar-Away Silicone and four minutes of preparation by a work study student. Based on the findings in Table 3, the cost of each electrode will be $7.29.[20]

Each vest is a modified version of an elastic neoprene vest created by Patagonia. Vests are available for both genders for $79.[7,29] The modified vest incorporates 16 square inches of neoprene (0.5 millimeters thick), 0.15 ounces of Aquaseal rubber sealant, and 30 minutes of preparation by a work study student.

The modified heart rate monitor is a basic chest monitor with transmitting device to the wrist. The estimated labor and components added to the heart rate monitor is $25.

TABLE 3: PER UNIT COSTS OF EACH COMPONENT

ECG Electrodes	
Convatec's Sur fit Durahesive Skin Barrier	$5.00
Vermed® SilveRest Resting ECG Electrode	$0.50
Scar-Away Silicone Sheets ($20.20/ Package, Package yields 16)	$1.26
Preparation by Work Study Student: (can produce 15/hr)	$0.53
Estimated Cost Per Electrode:	$7.29
Reusable Vest – Purchased, then modified	
Provider: Wetsuit Warehouse: Patagonia Vest	$79.00
Neoprene: 0.5 MM Black, Nylon Backing, 75.60/yard, 16 inches	$0.30
Aquaseal: 0.75 oz tube, 11.99/bottle : 5 Vests	$2.40
Preparation by Work Study Student (produce 2/ hr)	$4.00
Estimated Cost Per Vest:	$85.70
Heart Rate Monitor – Purchased, then modified	
Omron HR-100C Heart Rate Monitor	$34.99
Estimated labor and components added	$25
Estimated Cost Per Monitor	$59.99

IV2.3.2 FIXED

The fixed costs depend on whether a company is formed or if the UHRM device technology is licensed. Costs associated with starting a company greatly outweigh those with licensing. Leasing a 3,000 square foot office space approximately an hour from Boston, MA in the current market would be approximately $36,000 a year.[30] Leasing closer to a major city such would increase the cost per foot. A commercial landlord in the present market would agree to lease for one to three years, with the burden of costs associated with moving and developing the space on the tenant, as well as the monthly utilities and maintenance charges. These vary greatly depending on the space and its condition when the lease begins. Leasing a 3,000 square foot space in Manchester, NH for three years leads to total costs amounting to $100,000.

In addition to leasing commercial space, the company will need to register its intellectual property. The rates for IP consultants range from $150 to $1000 per hour, based on the attorney's experience, location, and special expertise, and the costs for registering a product range even more based on the nature of the invention and its complexity.[31] Furthermore, the involvement of the inventor in the patent application process is another cost variable. In the case of UHRM, the inventors have had no experience with registering intellectual property. Therefore, it is assumed that their reliance on an IP attorney will be high. With all these factors considered, the costs to register the patents for the invention total approximately $20,000.

In total, with necessary machinery, real estate, utilities, staffing, benefits, IP registration, and other general expenses, the startup cost is assumed to be around $500,000.[30]

Licensing would remove the need for most of the expenses above, relying mostly on the expertise of an IP consultant and an attorney who specializes in contracts. As mentioned above, the costs for registering the intellectual property will be around $20,000. The added cost for legal aid with the licensing agreements would bring the total to $50,000.

IV2.3.3 Garnering Financial Support

If UHRM is pursued as a commercial product, the company will need to raise capital to fund the project. Gaining venture capital support is never easy, however. The company will need to show the usefulness and profitability of the device while avoiding esoteric language. One option for gaining funding would be creating a pitch video (see attached video).

IV2.3.4 Break Even Analysis

The Break Even Analysis was conducted for each combination of market (technical diving and military) and strategy (entrepreneurship and licensing) to determine the number of customers required to become profitable, and, therefore, which scenarios would prove feasible when compared with the market sizes outlined previously. The break even analysis was more complex than the original equation given in Section II. This is because UHRM is actually three products, each with specific metrics for its utilization. For technical diving, it was assumed that for every vest which was purchased, the customer would also purchase a monitor and 30 electrodes over a span of three years. For military diving, vest to monitor to electrode ratio was 1:1:1200 for a three year span.

The break even analysis confirmed the feasibility of these markets by comparing the break even quantity of divers to the assumed market size. It also demonstrated that it in both markets, a start up would involve higher risk.

TABLE 4: ABBREVIATED BREAK EVEN MATRIX WITH MARKET COMPARISON

Market	Scenario	Package	Break Even Packages	Break Even Divers	Market Size	Share of Market
Technical Diving	Start Up	Starter Pack	2,100	2,100	260,000	0.8%
		Refill	4,200			
Technical Diving	License	Vest	1,200	1,200		0.5%
		Monitor	1,200			
		Electrode	36,000			
Military	Start Up	Vest Pack	2	40	1,000	4%
		Monitor Pack	2			
		Electrode Pack	80			
Military	License	Vest	21	21		2%
		Monitor	21			
		Electrode	25,200			

IV2.3.5 Return on Investment (ROI) Analysis

The ROI was used to determine which strategies would prove most profitable if pursued, assuming that 10% of the target market adopted the new technology over a span of three years, and that the market followed similar buying patterns as discussed in the Break Even Analysis. As shown below, pursuing the military market through a startup company is the most feasible option. It is important to remember that estimations of the military market were not authoritative, and a 10% penetration rate over three years is highly aggressive.

TABLE 5: ABBREVIATED ROI MATRIX

Market	Scenario	3 YR ROI
Technical Diving	Start Up	34%
Technical Diving	Licensing	11%
Military	Start Up	40%
Military	Licensing	19%

IV2.4 SWOT ANALYSIS

The SWOT analysis identified the strengths, weaknesses, opportunities, and threats of UHRM. Understanding these further underlined the feasibility for pursuing UHRM commercially.

TABLE 6: SWOT MATRIX

Strengths	Opportunities
• Unique • Inexpensive • First Mover Advantage	• Further Market Penetration • Patenting the detection method • Pursuing other markets
Weaknesses	**Threats**
• Under-developed technology • Lack of awareness of product • Reliance on pre-fab goods	• Current Competition • Future Competition • Fluctuations in economy

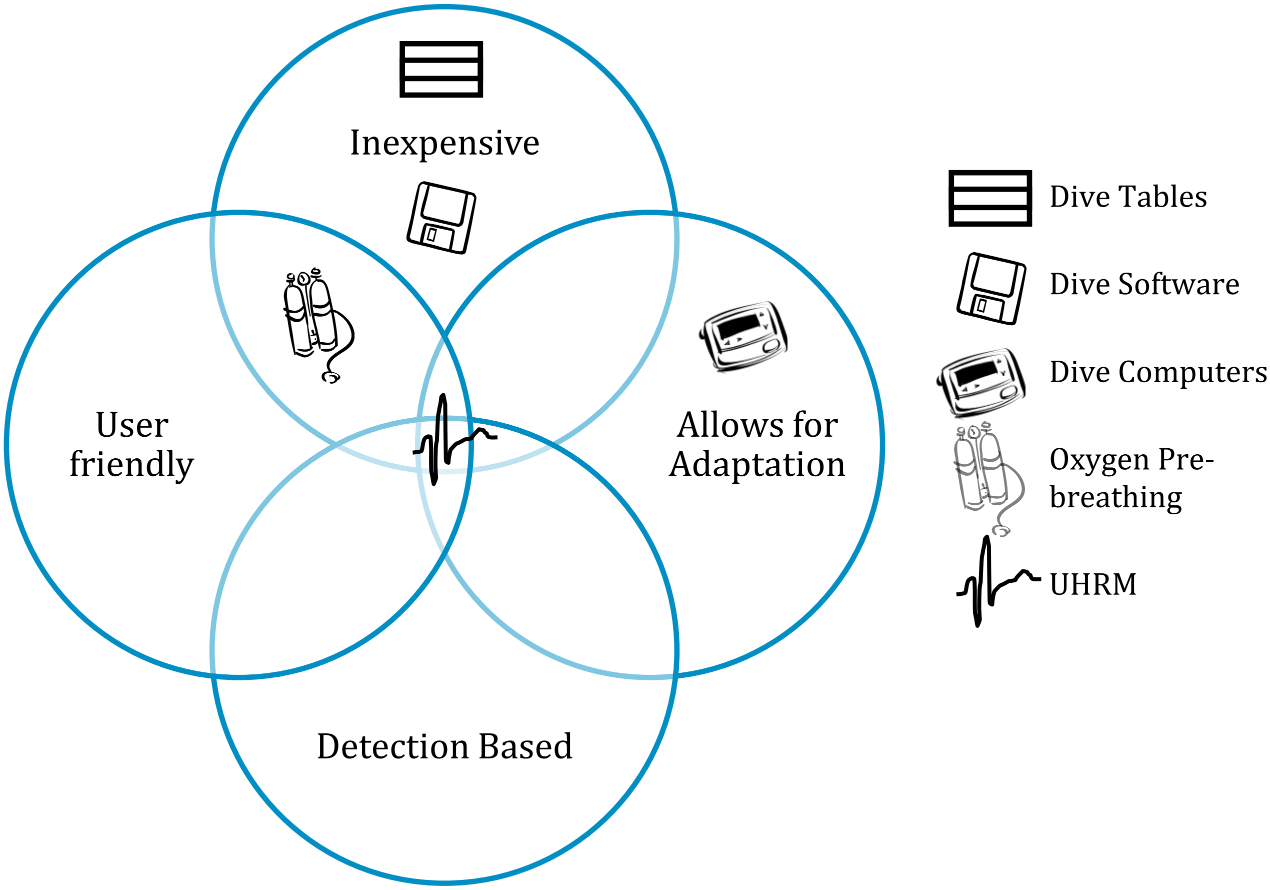
IV2.4.1 STRENGTHS

UHRM's key strengths are its uniqueness, low cost, and first mover advantage with respect to the SCUBA market.

IV2.4.1.1 UNIQUE AND INEXPENSIVE

UHRM allows for real time adaptation to the circumstances and symptoms exhibited from the diver. This allows a greater likelihood of preventing DCS altogether, and enables the diver to react to changes in his physical condition due to fatigue, etc. Underwater heart rate monitoring also exhibits all of the positive qualities of its competitors (Figure 4: Venn Diagram of UHRM and its Competition).

FIGURE 4: VENN DIAGRAM OF UHRM AND ITS COMPETITION



IV2.4.1.2 First Mover Advantage

Because the UHRM device is the first of its kind, it will experience an advantage as it enters the market, referred to as the "first mover advantage." Being the first to enter the market creates barriers to entry such as experience benefits, economies of scale, reputational effects, and technological leadership.[32] These advantages can lengthen the time between the UHRM market entry and any competitors which follow. During the period in which the UHRM device is the only which uses pathologic detection methods to prevent DCS, the company will experience the equivalent of a monopoly.

IV2.4.2 Weaknesses

UHRM is at a disadvantage because it is a poorly publicized, under-developed technology which relies on goods which have already been fabricated.

IV2.4.2.1 Under-developed Technology

The present UHRM device is inadequate at its current state. The waterproof electrodes and the vests are the only components which have been developed for the product, thereby making it under-developed. A heart rate monitor using the R-R interval analysis needs to be invented before the device will be marketable. The device has not been tested to determine its limits, including depth, temperature, and length of time worn. Because of this, it is impossible to ascertain that it functions they way it's designed to. It is also impossible to establish how much real world improvement UHRM can make.

Without the heart rate monitor and proper testing, the UHRM invention is not eligible to be patented. Most importantly, in its current state, UHRM is not viable for any market.

IV2.4.2.2 Lack of awareness

There is little awareness of the capabilities of UHRM. Because of this, it could be difficult for the product to enter the marketplace. Divers may question the rationale behind purchasing new equipment when what they currently use is minimally adequate. The firm will need to publish and publicize information regarding the benefits of switching to detection.

IV2.4.2.3 Reliance on Prefab Goods

The product currently relies on other existing products. This could prove helpful to the company as it first starts to manufacture its products. However the costs to create UHRM will be significantly higher. In addition, if a supplying company changes its products, UHRM will have to adapt to those newer products, perhaps creating delays in device manufacturing, and unsatisfied customers who must learn to use new devices.

IV2.4.3 Opportunities

The company currently has the opportunity to patent UHRM, pursue the SCUBA market further, and investigate other markets which could benefit from the technology.

IV2.4.3.1 Patenting UHRM

The company has the opportunity to protect several aspects of the UHRM device as intellectual property provided that it can prove that the device is new, non-obvious, and useful.[33]

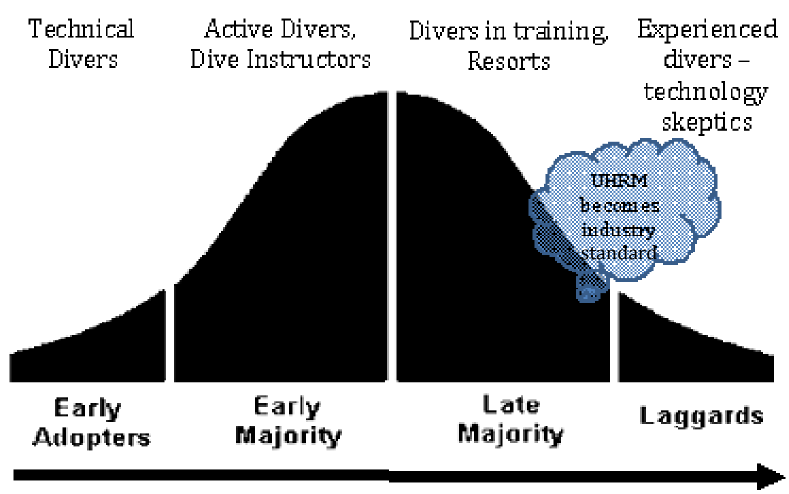
- The design of the waterproof electrodes
- The use of R-R Interval Analysis to detect DCS
- The configuration of the entire UHRM system

The company also has the opportunity to trademark UHRM.[34]

IV2.4.3.2 Further Market Penetration

After successfully penetrating the technical diving and military diving market segments, the company could migrate to pursuing secondary markets. In the case of recreational diving, the company could market towards active divers and dive instructors before eventually reaching out to introductory divers and resort diving providers. After pursuing military diving, the company could pursue commercial diving (see below).

FIGURE 5: HIGH TECH LIFE CYCLE IN RECREATIONAL SCUBA DIVING MARKET



IV2.4.3.3 PURSUING OTHER MARKETS

UHRM could have several applications outside of the SCUBA diving industry. Because decreased heart rate variability is a prognostic marker for cardiovascular diseases such as diabetic autonomic neuropathy, hypertension, myocardial infarction, and heart failure, the device could prove useful for individuals who are indicated to be at high risk for cardiovascular disease.[35] High risk individuals participating in aquatic exercises could use the device to monitor their heart rate variability, thereby catching a cardiac episode before it happens. Competitive long-distance swimmers could use UHRM to detect cardiovascular complications during rigorous aquatic exercise, but the device would need to be modified aerodynamically.

IV2.4.4 Threats

UHRM is threatened by its current and future competition, and fluctuations in the economy.

IV2.4.4.1 Current and Future Competition

UHRM currently faces competition from navy dive tables, dive planning software, and dive computers. In the future, it could also face competition from oxygen pre-breathing, although this method has not been widely accepted by the diving community.[5,36]

IV2.4.4.1.1 Navy Dive Tables

The Navy Dive Tables, as mentioned above, are charts with prescriptive guidelines regarding how long a diver should spend at each decompression stop in order to allow the nitrogen to escape from the body rather than bubbling up.[2] In addition to the Navy's tables, most dive companies create their own versions.

Amazon sells waterproof dive tables for $10.95, and it is fairly easy to find an electronic copy at no cost with a simply internet search. (Navy dive table for 110, 120, and 130 Ft Dives retreived from Google Image Search)

FIGURE 6: NAVY DIVE TABLE FOR 110, 120, AND 130 FT DIVES RETREIVED FROM GOOGLE IMAGE SEARCH

Table 9-8. U.S. Navy Standard Air Decompression Table (Continued).

Depth feet/meters: **110 / 33.1**

Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 50 / 15.2	40 / 12.1	30 / 9.1	20 / 6.0	10 / 3.0	Total decompression time (min:sec)	Repetitive group
20						0	3:40	*
25	3:20					3	6:40	H
30	3:20					7	10:40	J
40	3:00				2	21	26:40	L
50	3:00				8	26	37:40	M
60	3:00				18	36	57:40	N
70	2:40			1	23	48	75:40	O
80	2:40			7	23	57	90:40	Z
90	2:40			12	30	64	109:40	Z
100	2:40			15	37	72	127:40	Z

Depth feet/meters: **120 / 36.5**

Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet/meters) 70 / 21.3	60 / 18.2	50 / 15.2	40 / 12.1	30 / 9.1	20 / 6.0	10 / 3.0	Total decompression time (min:sec)	Repetitive group
15								0	4:00	*
20	3:40							2	6:00	H
25	3:40							6	10:00	I
30	3:40							14	18:00	J
40	3:20						5	25	34:00	L
50	3:20						15	31	50:00	N
60	3:00					2	22	45	73:00	O
70	3:00					9	23	55	91:00	O
80	3:00					15	27	63	109:00	Z
90	3:00					19	37	74	134:00	Z
100	3:00					23	45	80	152:00	Z
Exceptional Exposure										
120	2:40				10	19	47	98	178:00	**
180	2:20			5	27	37	76	137	286:00	**
240	2:20			23	35	60	97	179	398:00	**
360	2:00		18	45	64	93	142	187	553:00	**
480	1:40	3	41	64	93	122	142	187	656:00	**
720	1:40	32	74	100	114	122	142	187	775:00	**

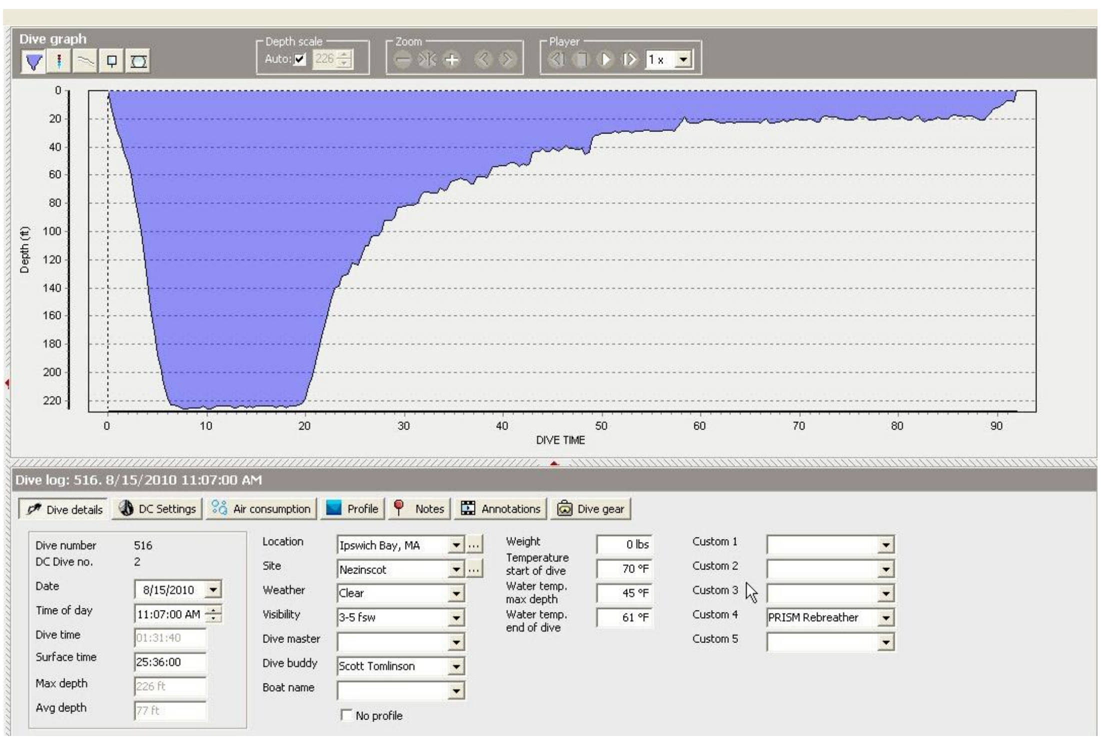
The dive table's competitive advantage is its cost, which is significantly lower than competing products. The disadvantages with using the dive table are that it is complicated, and is not usually portable underwater. The diver must practice discerning guidelines from the table for it to be effective and must memorize his plans before he dives.[2]

IV2.4.4.1.2 DIVE SOFTWARE

Dive planning software takes the inputs provided by the diver and uses mathematic calculations to determine the best decompression plan based on the described dive.[5] Divers can input information regarding length and depth of dive, air concentrations used, physical fitness, height and weight, and many other criteria. Software can be downloaded for free online and is available for both PCs and Macs, and also Android capable devices. The screenshot below is a typical technical dive that a technical diver might take in the Northern Atlantic.

The advantage of dive software is that it is free or relatively inexpensive, and it allows the user to extensively plan ahead of time with his dive. Dive software is not adaptive in real time, however. Once the diver submerges, he must follow the plan which he entered into the software to improve his safety.

FIGURE 7: A SCREEN SHOT OF A TECHNICAL DIVE SOFTWARE[5]



IV2.4.4.1.3 Dive Computers

Dive computers are portable devices which use mathematical models of human tissue compartments and gas exchange processes to determine the theoretical amount of nitrogen uptake during a dive, displaying what is referred to as a decompression status.[37] These devices use real time pressure gauge data during the dive in concurrence with the time to make predictions, instructing the diver how long to spend at each decompression stop.

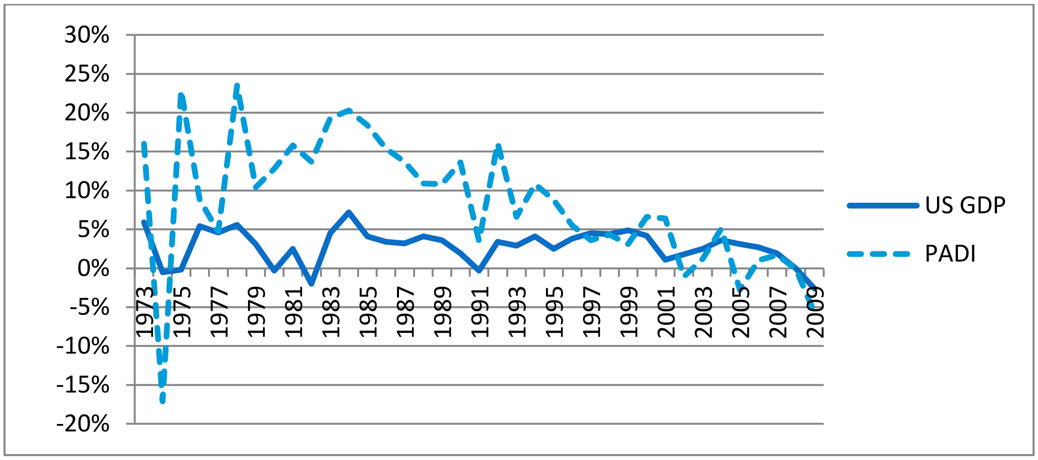
The greatest strength of the dive computer is also the greatest weakness: its complexity. The dive computer's integration with real time pressure data as well other inputs requires more effort from the user to learn its functions. This is even truer for dive computers rated for technical diving, which incorporate the type of air the diver is breathing.[5] This complexity also yields a higher price. There are only three dive computers on the market rated for technical diving, all of which retail for $1,000 or more.

Most recently a dive computer with an integrated waterproof heart rate monitor was patented.[38] The device's software factors the heart rate into its algorithms as it calculates the probability DCS. Although this device is similar to UHRM, it still relies on prediction algorithms rather than detection. This new dive computer could prove to be the largest competitive threat to UHRM because of their aesthetic similarities.

IV2.4.4.2 Economic Factors

Diving is easily affected by the state of the economy because of its status as a luxury activity. The chart below demonstrates this by comparing the growth in PADI certifications each year with the growth in the United States Gross Domestic Product (GDP). During economic downturns, PADI experiences less growth. As such, it can be assumed that divers will dive less frequently and purchase less SCUBA related merchandise during times of economic hardship.

FIGURE 8: US AND PADI GROWTH PERCENTAGE BETWEEN 1973 AND 2009[8,39]



Fluctuations in GDP are mimicked by fluctuations in PADI certifications. This is especially evident between 1978 and 1995 (Figure 8).

V. CONCLUSION/ RECOMMENDATIONS

UHRM has a promising future in the SCUBA industry with a potential market of 1.2 million divers worldwide. Although there is competition in the area of preventing DCS, UHRM's advantages outweigh those of the other products reviewed in this report. The technology offers unique advantages that no other product currently in the market or in known-development is capable of: the ability to detect the onset of DCS rather than predict it. These devices have the potential to prevent the many injuries and fatalities apparent in SCUBA diving related to DCS. If the UHRM devices can be successfully developed and tested, and are marketed in the ways outlined above, it is likely that they will succeed as a profitable endeavor, with the possibility of granting investors up to an aggressive 34% return on their investment.

Analysis has shown that UHRM technology has a promising future, even with the limited scope of development completed to date, however a modified heart rate monitor must be developed for the device to be marketable. In addition, the technical diving community and military must be made aware of the advancements made by the technology. Most importantly, it is critical that the intellectual property associated with UHRM is registered and protected.

In conclusion, there is a market for at least 1.2 million divers that can benefit from UHRM which offers unique advantages, such as detecting the onset of DCS and allowing the user to adapt in real time based on those detections. If the UHRM device can be completely developed and tested and marketed for prices comparable to those discussed in this report, then this technology will be successful in the SCUBA industry. Therefore UHRM is worth pursuing further.

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VII. Appendix

VII1. Heather Knowles. Personal Communication. 2011

From: Heather Knowles [mailto:info@northernatlanticdive.com]
Sent: Sunday, October 02, 2011 9:30 AM
To: King, Katherine E
Subject: RE: Senior Thesis Project -- Please Help!

Hi Katie,

Thanks for sharing these data--it's very interesting to me!

The reason we wear drysuits is because the water around here is fairly cold--ranging from 35-45 F on the bottom with thermoclines ~20-40 feet 50-60 F range (in the summer). We are sometimes in the water for as long as 2-2.5 hours and so exposure becomes a problem, and drysuits are more comfortable. Attached is an average deeper dive -- this was done on a closed circuit rebreather.

Anyway, I think the sport diving market would probably not be terribly interested electrode system in general, but technical divers would be, especially if there was some way to help prevent DCS by using it. Many of us have experienced varying degrees of DCS. It is not uncommon in extreme exposure technical diving. Most of the time it manifests in the form of Type 1 DCS with skin involvement. It is typically treated with O2 and aspirin unless severe enough to require recompression treatment (Mass Eye and Ear has a mono place chamber).

Anyway, your research sounds fascinating and I would be interested in learning more. If you want to use our group for any experimentation, we'd be happy to participate. However, in deeper diving I would have concerns about doing O2 pre-breathing prior to diving to depth--the main reason being concern about O2 exposure %CNS and OTU onloading.

Thanks for sharing this info--I'm interested in deco theory in general, so this has been great.

Heather

From: "King, Katherine E" <kate.e.king@WPI.EDU>
Sent: Wednesday, September 28, 2011 4:46 PM
To: "info@northernatlanticdive.com" <info@northernatlanticdive.com>
Subject: RE: Senior Thesis Project -- Please Help!
Hi Heather,
I understand your points about Oxygen Pre-breathing. I was mostly researching that to do compare what the competitive cost of the electrode system might be. I can instead compare the costs of the electrodes to an investment of dive software or something similar. Basically, we need to know what a product competitor would be so I can tell the design group "This is how much the electrode can cost but still be sold."

As for DCS with heart rate, I'll do my best to explain what I can:

My project advisor here at WPI did some experiments with the Navy to predict DCS from electrocardiogram data by monitoring pigs while they sat in a hyperbaric chamber. He eventually was able to develop a method that looks at the heart rate variability, or in other words, the changing interval between each heartbeat. To be perfectly honest, I don't understand the computer science behind the analysis, but I can show you the before and after charts if you're interested.

The left side is just a normal electrocardiogram on the pig before and after DCS. As you can see, based on the ECG data, there is no huge discernable difference, although the R waves (the giant peaks) are pretty elevated.

On the right, we have the analysis which looks at the interval between each R wave, referred to as the R-R interval. The RR interval is the way we calculate the heart rate, because the R is almost always the easiest to pick up of the ECG data. The top graph is the normal variability experienced, creating the lub-dub effect that you hear when you listen with a stethoscope. The bottom graph, however, shows the heart rate interval post DCS. Professor Chon relates these changes to problems with the balance between the parasympathetic and sympathetic nervous system. (I think)

The fact that you use dry suits means that the waterproof factor would not matter in your case. We would be planning to place the entire system in a vest that goes under the rest of the divers' apparel. Prof. Chon's primary target audience for this would be the Navy divers of the Special Operations teams – that's all he's given us to work with so far. He's presenting to our group next week to explain more. Should I fill you in on what he tells us?

By the way, what are the advantages of dry suits?

As for technical divers and their application, I'm looking into that population as a secondary market to write about in my thesis. If they end up not being a secondary market, I will write that instead.

Thanks so much for your help,
I hope this is somewhat interesting for you as well. :)

Katie

From: Heather Knowles [mailto:info@northernatlanticdive.com]
Sent: Tuesday, September 27, 2011 7:34 PM
To: King, Katherine E
Subject: RE: Senior Thesis Project -- Please Help!

Hi Katie,

Sorry for the delay in replying.

Interesting paper--and while it may have validity from a scientific standpoint, O2 prebreathing would be a very impractical and potentially unadvisable practice in actual decompression diving. Some of this has to do with elevated partial pressures of oxygen and exposure to O2 (that affects accumulation of oxygen toxicity units, for example)--the same reason that prebreathing at depth showed greater benefit than at the surface (at 20 feet, oxygen has a partial pressure of 1.6). These studies were also limited to short non-decompression dives. Anyway, interesting paper, but this simply isn't a practice in sport diving. I would recommend looking at a few sites:

http://www.hhssoftware.com/v-planner/
http://www.gap-software.com/support/documents.html

These links contain some papers that might be useful to you.

I am really not sure how a waterproof heart monitor system would be useful--maybe I need to learn more about it. We wear drysuits for one. Most of our dives are longer decompression dives in cold water. So something like this would be under several layers of thermals and a drysuit. How would measuring heart rate correlate to risk of DCS? It is known that exertion raises risk of DCS because of increased inert gas uptake and CO2 production... but what's the theory here?

Heather

From: "King, Katherine E" <kate.e.king@WPI.EDU>
Sent: Friday, September 23, 2011 10:03 AM
To: "info@northernatlanticdive.com" <info@northernatlanticdive.com>
Subject: RE: Senior Thesis Project -- Please Help!

Heather,

I appreciate your response and I apologize for not returning a reply sooner – things are really busy this time of year with classes, research, and a job hunt. In regards to your statement that OPB has nothing to do with DCS, I beg to differ. Perhaps this is just my understanding from only studying SCUBA out of a book, however, studies have shown that oxygen pre-breathing can be a useful endeavor, such as this one. Again, I've never actually dived, so you're certainly the more authoritative source in this case.

Anyway, I will definitely look into the software that you discussed below. Do you see any type of opportunity in your line of work for a waterproof heart rate system? Or, do you think that this wouldn't be a profitable endeavor? You can answer the latter, it's won't hurt my grade, I promise. My main job is to see whether or not the device would stand a chance. If it doesn't, I'll write that it doesn't.

Thanks again,
I look forward to hearing from you.

Katie

From: Heather Knowles [mailto:info@northernatlanticdive.com]
Sent: Wednesday, September 21, 2011 6:16 PM
To: King, Katherine E
Subject: RE: Senior Thesis Project -- Please Help!

Hi Katie,

Thanks for contacting us. It sounds like an interesting project you are working on. We do not fill tanks for the public, but just as a general comment, you need to have the appropriate certification to obtain nitrox or 100% O2 from any dive store, so you may have difficulty obtaining this if you are not certified for nitrox or technical nitrox. With regard to your DCS project, there are many reference books out there on decompression diving and risk factors for/prevention of DCS, but I can tell you that Oxygen pre-breathing prior to diving has next to nothing to do with it. The US Navy dive tables are also a very antiquated tool for dive planning. I don't know anyone who actually uses them. Nearly all sport divers conducting decompression dives use software-based dive planning programs such as a Haldane based dissolved gas Buhlmann model with variations or a dual phase bubble model such as RGBM or VPM. Decompression sickness is multifaceted and is influenced by everything from personal physiology, pre-existing medical conditions such as PFO, physical/mental stress during the dive, water temperature, CO2, nitrogren narcosis and the aggressiveness of the dive plan and decompression profile used. It is also affected by gas selection, ascent rates and ultimately, good or bad luck. It is prevented by planning well, executing the dive and ascent rates properly, aiming for low-risk profiles for decompression, proper fitness and hydration, and minimizing exertion during and after the dive. There are several forms of DCS--Type 1, Type 2 are the main ones and they manifest for different reasons. So, this is a very complex and interesting topic, but not a simple one. I can probably point you to some reference material/books if that would be helpful.

Hope this helps,
Heather Knowles
NAUI CCR Trimix Instructor 42995

VII2. Sebastian Courtney, Justin Bales, Alex Reeves. Personal Communication. 2011

- Detect the onset of Decompression Sickness
- Using Hydrolectrode electrodes
- Vest: Patagonia, $79 on Wetsuit Warehouse
  - Rubber sealant
  - Waterproof neoprene material – 16 inches
  - Pockets for monitor and electrodes
- Monitor – Not designing, but necessary
  - Modified existing technology using RR Interval Analysis
  - Most likely a two piece system
- To be tested in C2012 with Holter Monitors

VII3. Pamela Halvorsen. Personal Communication. 2011

- Depends on location – I own space 1 Hour from Boston
- $12/Square Foot/Year
    - Tenant pays for remodeling, maintenance and utilities
    - Startups usually agree to 3 yr lease
- For established companies, bargaining is harder – it's a buyer's market
    - We will pay for remodeling, etc.
- One advantage is that most realtors have extra empty space, so as a start up grows, they can secure more floor space
- Other costs for start ups
    - Licensing, utilities, employees, workman's comp, benefits, etc

VII4. Gerry Blodgett. Personal Communication. 2011

First of all, although some lawyers in the personal injury field (car accidents, etc.) do things on a 1/3 basis, patent attorneys only do that in VERY unusual cases.

Patent attorneys work on a hourly basis, in the range of $150/hour to $1000/hour, depending on location, experience, and special expertise.

There is a huge range of costs, depending on the nature and complexity of the invention, so it would be helpful if you would give me summary of the invention in question. The range of innovation complexity in BME is broader that any other field I know.

Another very important variable is the involvement of the inventor. Some on my inventors practically write the patent application themselves and just use me to fine tune. Others tell me the basic idea and leave all the work to me.

VII5. Equations Explained

VII5.1 Break Even Analysis (Equation 1)

The break even analysis for this report was complicated because of the multiple products offered by the company. To account for this, the author chose to calculate the break even number of customers instead, basing this figure on the assumed product usage in each market. The formulas derived to reflect each market are below.

VII5.1.1 Technical diving via Start Up Company

$$x = \frac{C_{fixed}}{(P_{starter} + P_{refill}) - \left(C_{variable_{starter}} + C_{variable_{refill}}\right)}$$

$$= \frac{\$500{,}000}{(\$400 + \$200) - (\$305 + \$60)}$$

$$x = customers, C = Cost, P = Price$$

VII5.1.2 Technical Diving Via Licensing

$$x = \frac{C_{fixed}}{(P_v + P_m + 30 * P_e) - \left(C_{variable_v} + C_{variable_m} + 30 * C_{variable_e}\right)}$$

$$= \frac{\$50{,}000}{(\$90 + \$70 + 30 * \$9) - (\$80 + \$60 + 30 * \$8)}$$

$$v = vest, m = monitor, e = electrode$$

VII5.1.3 Military Diving Via Start Up

$$x = \frac{C_{fixed}}{(P_v + P_m + 20 * P_e) - \left(C_{variable_v} + C_{variable_m} + 20 * C_{variable_e}\right)}$$

$$= \frac{\$500{,}000}{(\$2{,}000 + \$2{,}000 + 20 * \$12{,}000) - (\$1{,}700 + \$1{,}200 + \$7{,}200)}$$

$$x = \frac{C_{fixed}}{(P_v + P_m + 1{,}200 * P_e) - \left(C_{variable_v} + C_{variable_m} + 1{,}200 * C_{variable_e}\right)}$$

$$x = \frac{\$50{,}000}{(\$100 + \$80 + 1{,}200 * \$10) - (\$85 + \$60 + 1{,}200 * \$8)}$$

VII5.2 RETURN ON INVESTMENT ANALYSIS (EQUATION 2)

The return on investment calculation also relied on the usage assumptions for each market, assuming that one tenth of the market purchased equipment over a span of three years. Therefore, the author divided the tenth by three to determine the number of customers who would purchase per year. The author also factored in the time it would take to use each product. For example, the starter pack offered to the technical diving market would last the average technical diver on average two years, meaning that the third year would be when they purchased the refill pack of ten electrodes.

VII5.3 BOYLE'S GAS LAW (EQUATION 3)

Boyle's Law of Gas and Pressure states that at constant temperature, the pressure *P* of a gas is inversely proportional with its volume *V,* thus the equation below, in which *k* represents a constant.[40]

$$PV = k$$

VII5.4 PARTIAL PRESSURE OF GAS (EQUATION 4)

The partial pressure of an element in a mixed gas is the percentage (or partial) of the substance multiplied by the ambient pressure of the mixed gas. This is represented by the equation below, where *P* and *n* stand for pressure and moles, and P_x and n_x stand for the partial pressure and partial of moles of an element *x.*

$$P_x = \frac{n_x}{n} * P$$

VII6. EXPANDED CHARTS

VII6.1 BREAK EVEN ANALYSIS

Market	Scenario	Fixed Costs	Package	Components	Unit Cost	Per Package			Assumed Ratio	Break Even		Market Size
						Cost	Price	Profit		Quantity	Divers	
Technical Diving	Start Up	$500 K	Starter Pack	1 Vest	$85	$305	$400	$95	1S:2R	2,100	2,100	264,000
				1 Monitor	$60							
				20 Electrodes	$8							
			Refill Pack	6 Electrodes	$8	$48	$120	$72		4,200		
Technical Diving	License	$50 K	Vest		$85		$90	$5	1V:1M:30E	1,200	1,200	264,000
			Monitor		$60		$70	$10		1,200		
			Electrode		$8		$9	$1		36,000		
Military	Start Up	$500 K	V. Pack	20 Vests	$85	$1,700	$2,000	$300	1V:1M:40E	2	40	1000
			M. Pack	20 Monitors	$60	$1,200	$2,000	$800		2		
			E. Pack	600 Electrodes	$8	$4,800	$12,000	$7,200		80		
Military	License	$50 K	Vest		$85		$100	$15	1V:1M:600E	21	21	1000
			Monitor		$60		$80	$20		21		
			Electrode		$8		$10	$2		25,200		

VII6.2 Return on Investment Calculation

Market	Scenario	Market Size	Divers/Year	Profit (In thousands)				Variable Costs (In Thousands)				ROI
				Year 1	Year 2	Year 3	Total	Year 1	Year 2	Year 3	Total	
Technical Diving	Start Up	264K	8800	$836	$836	$2,068	$3,740	$2,684	$2,684	$3,212	$8,474	36%
Technical Diving	License	264,000	8800	$220	$308	$396	$924	$1,980	$2,684	$3,388	$8,052	11%
Military	Start Up	1000	33	$162	$322	$482	$966	$112	$218	$324	$655	40%
Military	License	1000	33	$28	$41	$54	$164	$112	$218	$325	$335	16%